UPGRADING OF COAL DERIVED OIL BY INTEGRATING
HYDROTREATMENT TO THE PRIMARY LIQUEFACTION STEP

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The Bottrop Coal Liquefaction Project

The coal liquefaction project in the Coal Oil Plant in Bottrop, West-Germany, pursued the following targets:

- Demonstration of the improved Bergius-Pier hydrogenation technology on a technical scale
- Testing and further development of process-related and mechanical components
- Identification of environmental impact
- Development of design data base for a commercial unit and
- Generation of technical and operational know how.

The Pilot plant in Bottrop with a capacity of 200 t maf coal/day was erected in order to meet these targets.

The project was initiated in late 1977. After the engineering and construction phase, the plant came on stream in November 1981 and was operated up to May 1987.

The plant was layed out for

300 bar pressure,
475 - 490 °C reaction temperature and
the use of red mud as catalyst.

The project was pursued jointly by RUHRKOHLE AG and VEBA OEL AG. It was from the very beginning supported substantially by the State Government of Northrhine Westfalia and starting from 1984 also by the Government of the Federal Republic of Germany.

The initial process configuration is shown in Fig. 1. In this project phase the program focussed on the primary conversion of coal, using liquid phase hydrogenation reactors. This procedure yielded a raw oil from coal in the boiling range of naphtha and mid distillate, which was highly aromatic and had high contents of oxygen and nitrogen compounds. Secondary upgrading processes were applied in process development units, in order to convert the primary products into marketable fuels, e.g. gasoline, heating oil, kerosene and diesel fuel. Each of the different upgrading routes included severe hydrotreating as first step.

For this reason, the hydrotreating reactors were in 1986 directly linked to the primary conversion system as shown in the simplified flow scheme (Fig. 2). Contrary to the first mode of processing in which the net product fractions - naphtha and middle distillate - were subjected to upgrading processes in separate units, the total vaporised effluent from the liquid phase reactors including the vacuum gasoil fraction is in the integrated alternative fed to the hydrotreating stage, the so called "gasphase reactors". The new configuration makes use of the complete heat content of the LP reactor effluent and supplies reaction heat from the hydrotreater for the preheating of the fresh coal slurry, improving in this way the complete heat-exchange system thanks to the lower amount of external preheating fuel required. A further advantage of the integrated mode consists of the use of the high pressure of the first step and the secondary upgrading. Only a slightly higher pressure drop over the whole plant - caused by the additional equipment - has to be surmounted in the recycle gas compression.

The fact that the vacuum gasoil fraction from the coal liquids, which is in any case used as slurry oil for the fresh coal, was in the integrated process hydrotreated and hydrogen-enriched caused a large feed-back so the first process step and led to essential improvements in the performance, as described below.

Results

The total operating time of the plant for the coal liquefaction program amounted to more than 28.000 hours. During this time, appr. 166.000 t of coal were converted. Hard coal from the Ruhr Area, such as "Westerholt Coal" or "Prosper Coal", was usually used as feed. However, for comparison with competitive technologies, the program also included a batch of 4.000 t of Illinois No. 6 coal. The process mode with integrated hydrotreating was demonstrated for appr. 2.300 h with a total amount of 18.000 t of processed coal from the Westerholt mine. Fig. 3 compares the yield structures of the two processing modes. Due to the improved quality of the slurry oil, higher oil yields - 57,9 wt-% on maf coal against 50,6 wt-% - were obtained with substantially lower catalyst requirements, lower gas formation and lower amounts of hydrogenation residues.

The effect of integrated hydrotreatment on the sulfur- and nitrogen content of the liquid products is very high (Fig. 4) and leads from a raw oil to the expected refinery feedstock resp. blending component.

In addition, hydrotreatment adds hydrogen to the liquid products, which results in lower densities, aromaticities and higher heating values. The corresponding data for naphtha, middle distillate and vacuum gasoil - used as slurry oil - are listed in the following table:

Tab. 1: Comparison of product qualities

		Naphtha		Middle Distillate		VGO	
		LPH	Int. hydrotr.	LPH	Int. hydrotr.	LPH	Int. hydrotr.
C	(wt-%)	83.1	87.1	86.2	88.4	88.7	88.4
H	(wt-%)	11.8	13.6	9.3	11.9	8.1	11.7
C/H		7.0	6.4	9.3	7.4	11.0	7.6
Aromatic carbon	(wt-%)	29	14	59	21	67	20
Gravity	(kg/m^3)	813	722	979	912	1066	955
Lower heating value	(MJ/KG)	40.2	42.7	39.1	41.3	38.9	40.8

As mentioned above, the new slurry oil quality provided various improvements for the whole process. The hydrotreated vacuum gasoil made it possible to operate the liquid phase hydrogenation section at more moderate conditions. In addition to smaller catalyst requirements, it was possible to reduce the reaction temperature in the liquid phase reactors for 10 - 15 K, which was finally the reason for the lower gas formation and the resulting reduction in the specific overall hydrogen consumption.

While the initial hydraulic conditions in the slurry preparation, the slurry feed system and the preheating section were maintained, the lower density and viscosity of the slurry oil enabled a considerable increase of the coal concentration in the slurry from 40 % to more than 50 %, as well as a raise of the total coal throughput.

As the integrated mode of operation condenses only hydrotreated products instead of the raw materials, the phenol load in the process water stream which is separated from the condensate is reduced to zero. This makes the process water treatment much easier.

A further advantage obtained by the integration of hydrotreatment into the liquefaction process which deserves mentioning is the availability of the reaction heat from the hydrotreater for the whole process. This led to a new concept for the preheating section, shown in principle in Fig. 5. In the original concept, the mixture of slurry and hydrogenation gas is heated in a series of heat exchangers and has to get the required final temperature by passing a gas-fired preheater. This system was very sensitive against deposit and coke formation, especially at the high temperatures prevailing in the preheater tubes. After the integration of the hydrotreating section it was possible, by adding adequate heat-exchanger capacity, to preheat the total amount of slurry together with a small volume of hydrogenation gas - necessary to prevent coking - to an extent that made the us of an additional preheater superfluons. The lacking heat requirement was introduced into the system by overheating the main stream of hydrogenation gas in a separate line by heat exchange and the use of the preheater capacity. With this concept preheater fouling is no problem anymore. To conclude it can be said that the direct connection of the hydrotreating step to liquid phase hydrogenation provided a large improvement for the whole process and yielded products which can be directly fed to refinery streams. The naphtha fraction can be introduced into a refiner/reformer system producing high octane premium-grade motor fuel. The middle distillate fraction may be used as blending component for light heating oil or graded up to diesel fuel by means of ignition accelerators.

Current Use of the Bottrop Plant

The coal liquefaction program in the pilot plant in Bottrop was terminated in May 1987 at a level of technical development and know how which enables the operating companies to design and operate such plants on a commercial scale. The increase in know how which could have been gained from a further continuation of the program would not have justified the financial effort.

However, to keep the technical and operational know how alive and to maintaining the availability the plant for future coal liquefaction requirements, the two companies decided in agreement with the supporting authorities involved to modify the plant for the conversion of vacuum residues from refineries by means of the VEBA-Combi-Cracking process which has the same technological roots as coal liquefaction. The process principle in comparison to that of coal liquefaction is shown in Fig. 6.

The plant capacity for residue conversion amounts to 3.500 bpd of vacuum residue. At a conversion rate of 92 % the productive amounts for:

900 bpd naphtha
2.400 bpd middle distillate and
600 bpd vacuum gasoil

After revamping in the remainder of 1987 the plant was recommissioned in January 1988 with its new feedstock. It is aimed that the future operation will be performed under commercial terms and conditions.

The specific equipment for coal liquefaction is preserved and can at any time be reactivated for coal liquefaction or even coprocessing.

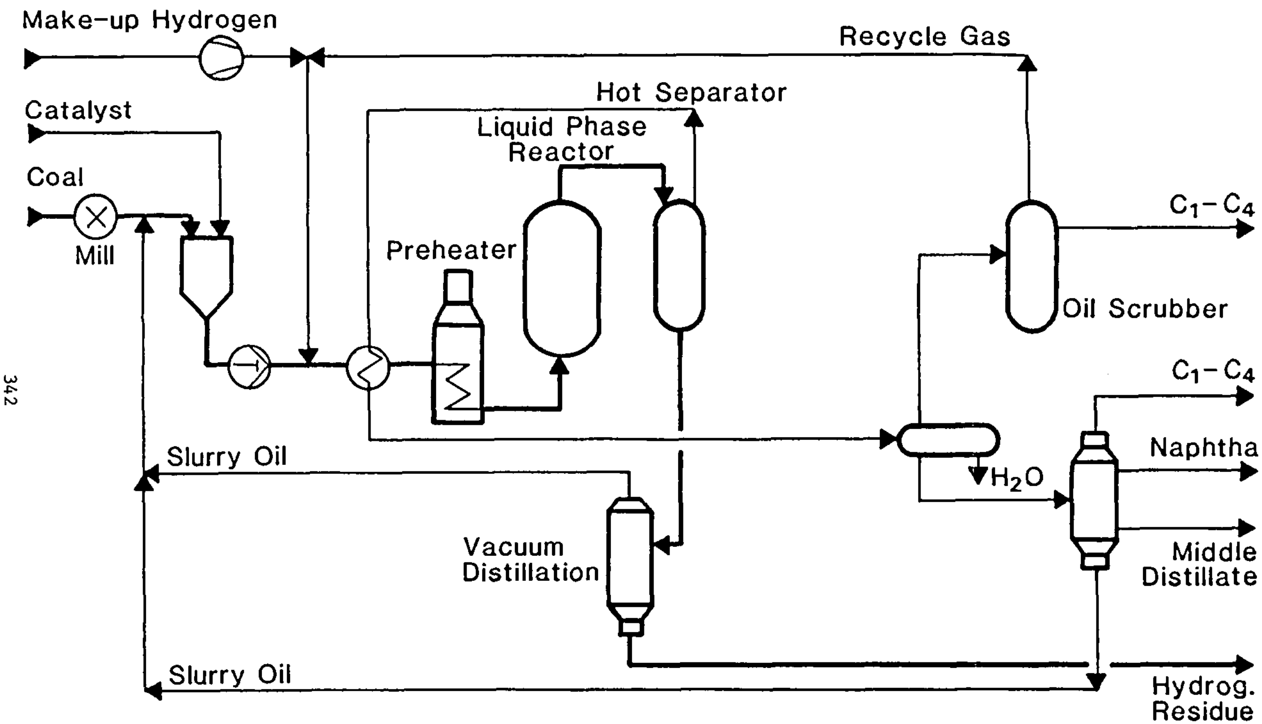

Fig. 1: Liquid Phase Hydrogenation - Initial Process Configuration

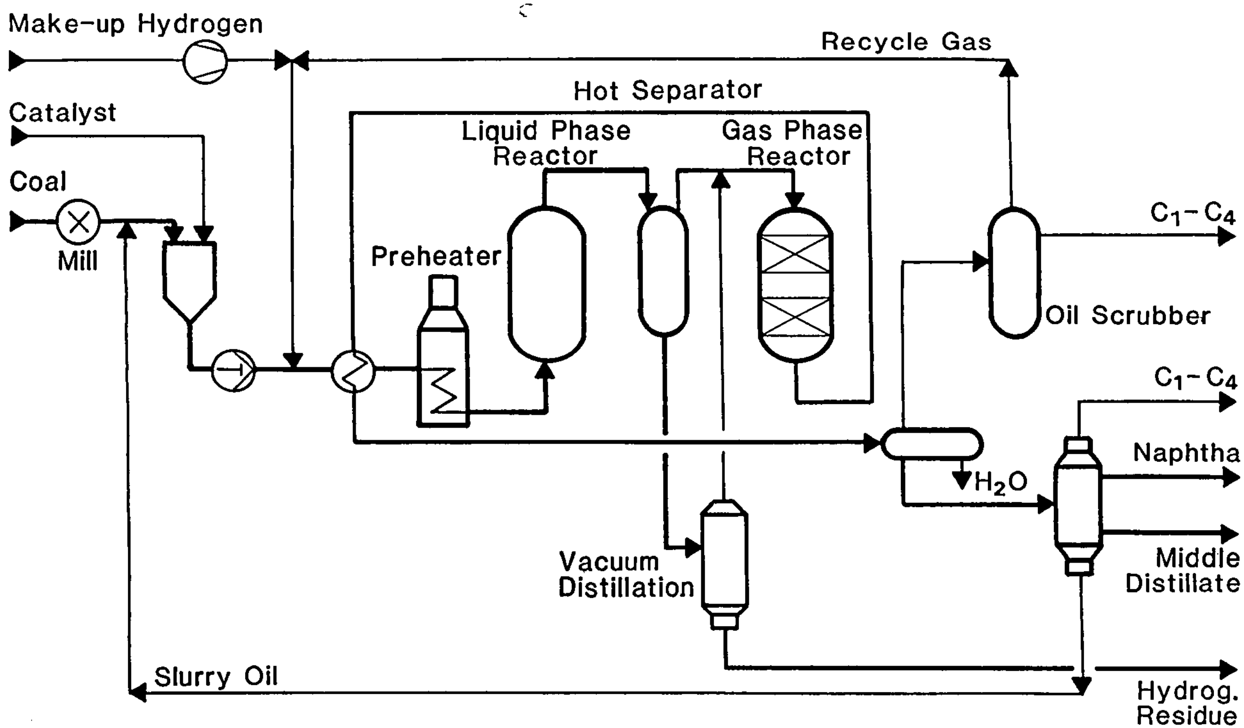

Fig. 2: Liquid Phase Hydrogenation with Integrated Hydrotreatment

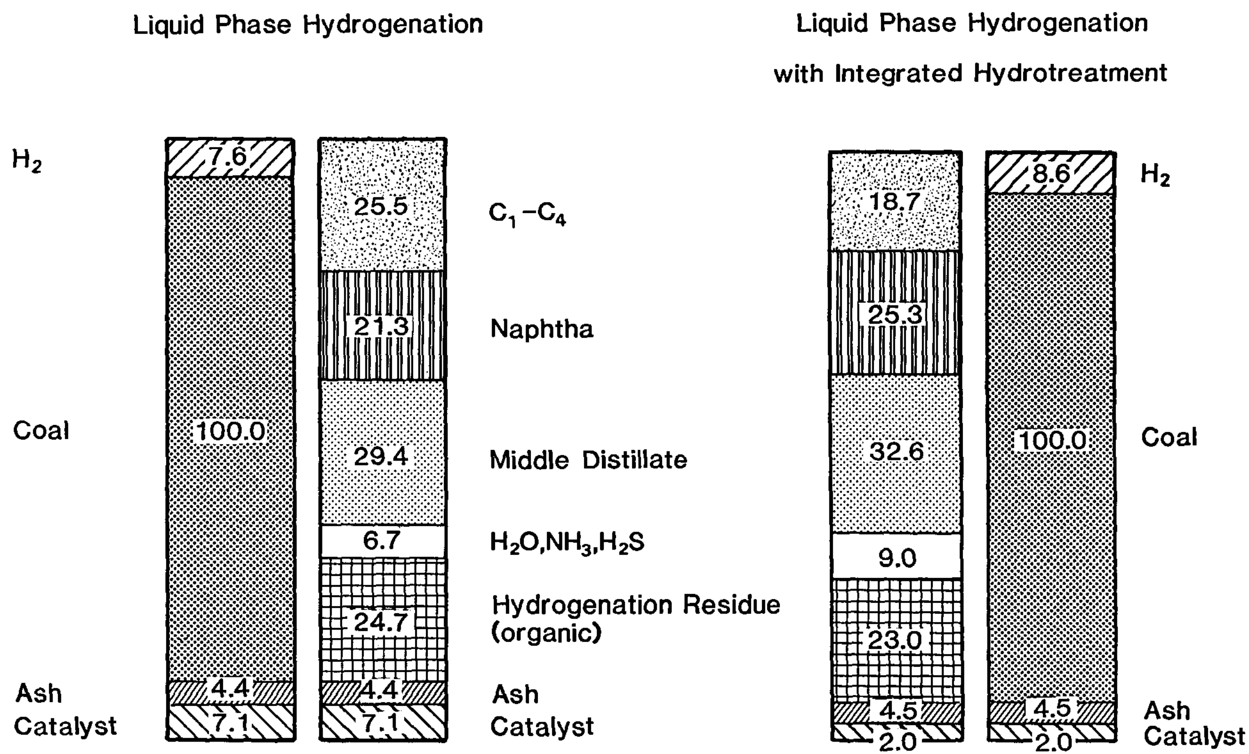

Fig. 3: Comparison of the Yield Structures for the two Process modes

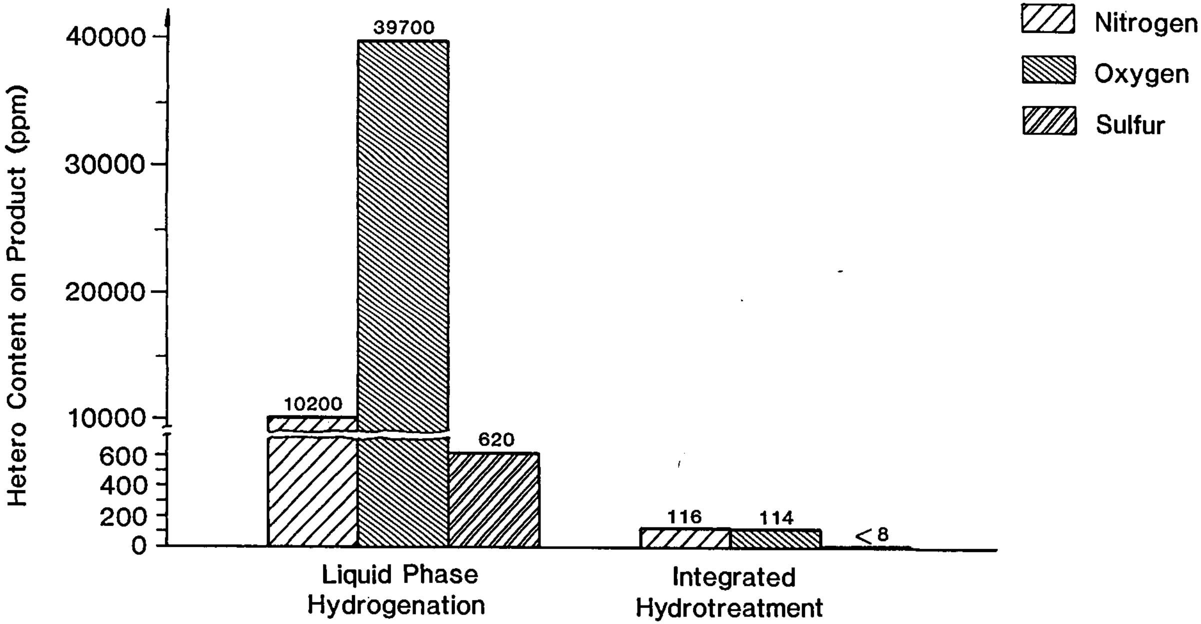

Fig. 4: Hetero Content in Liquid Products

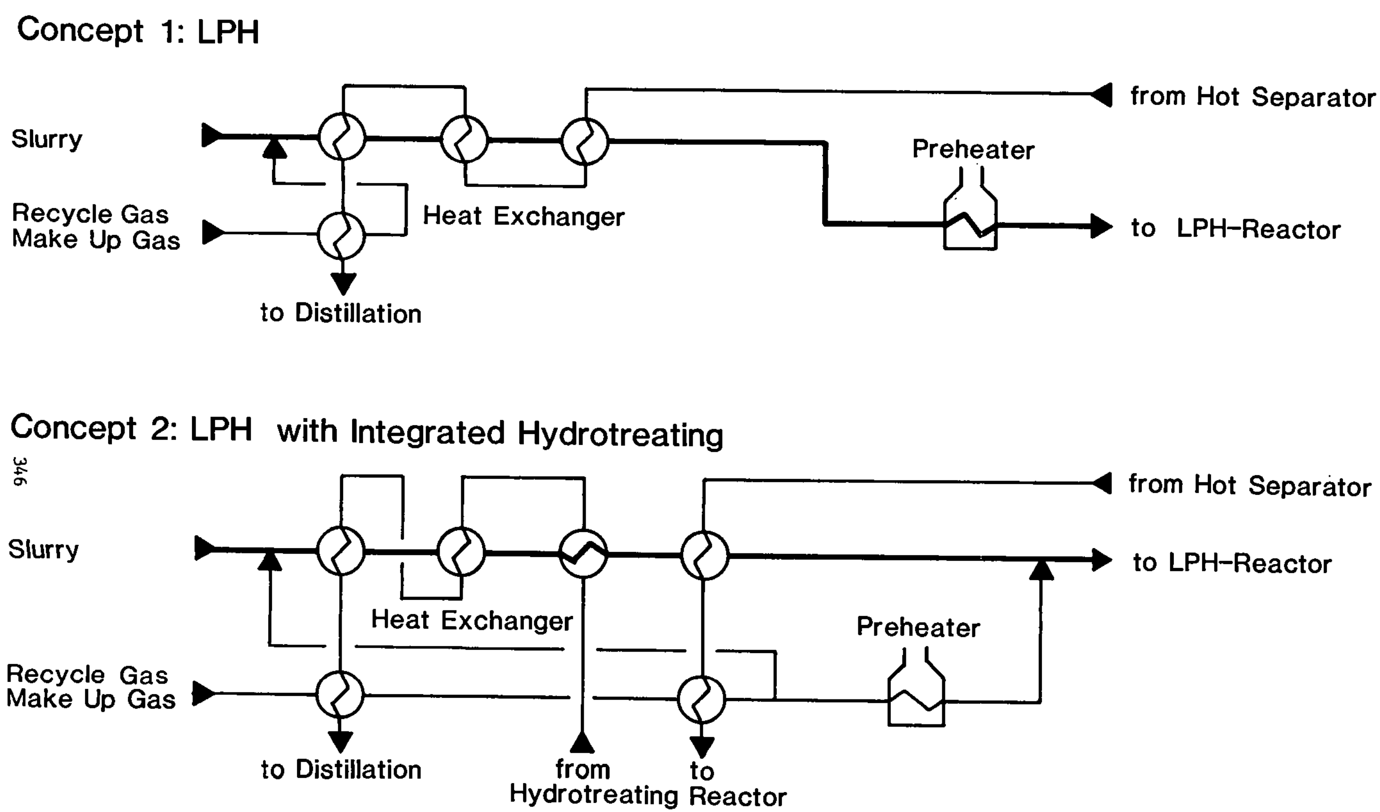

Fig. 5: Preheating Section

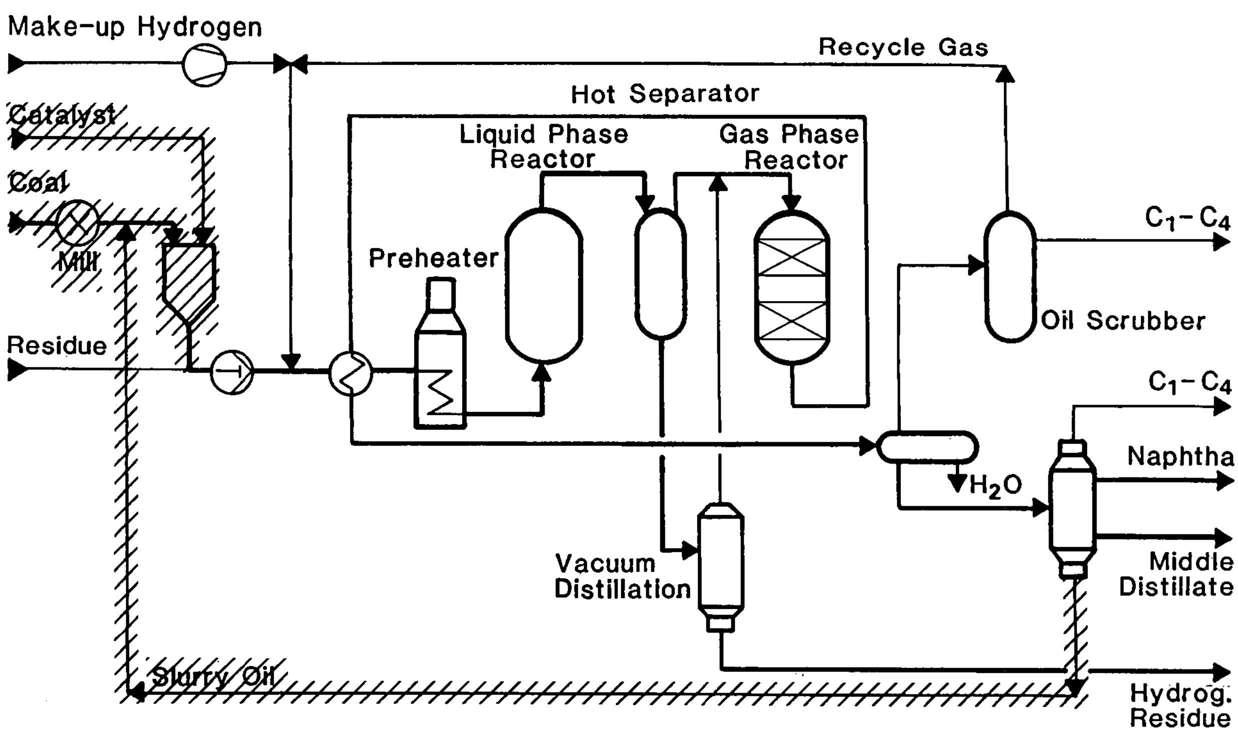

Fig. 6: Coal Liquefaction Plant Bottrop - Residue Conversion Mode